V/f Control of Five Phase Induction Motor Drive Fed From Cascaded H Bridge Multilevel Inverter

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Abstract—Multilevel inverter has its own advantages over normal inverters for higher voltage applications. Multilevels are realized by different techniques such as Flying capacitors, Neutral point clamp capacitor, Cascaded H-bridge and Packed U-cell. In this paper five level voltage is modulated for five phase induction motor drive applications. Multilevel inverter for multiphase drives has combined advantages of multilevel and multiphases, which makes the system an excellent solution for higher voltage applications. In this paper cascaded H-bridge inverter topology is considered for the five phase five level output voltage formation. The five phase drive is fed from the inverter to perform the volts/hertz control. The machine runs at different load conditions to verify the modulation technique.

Keywords—Cascaded H bridge inverter; Multilevel, Five Phase Induction motor; Volts/Hertz Control.

I. INTRODUCTION

Drives with a number of phases, more than three are receiving increased attention from the industry and academia due to their advantages associated with their three-phase counterpart, in high power drive applications, particularly where reliability is a key concern. In addition to enhanced reliability, multiphase drives also have significant advantages as compared to three-phase [1]-[4], which can be realized as:

- Reduction in the current ratings of power switches, as there is the possibility of splitting the power rating into more than the three phases. Therefore, they can be used for higher power applications.
- A significant improvement in the fault tolerance of the drive.
- Improved efficiency of multiphase drives due to reduced space harmonic content of the magnetomotive force.
- Torque pulsation reduction.

Due to the above advantages, multiphase drive systems can be used in many industrial applications such as high power industrial applications, locomotive traction, electric ship propulsion, etc [1], [5]-[6], making them attractive for many Propulsion [1-3].

Moreover, Reduced per phase power significantly reduced the semiconductor components current-rating. Additionally, ‘d’ and ‘q’ current are still available for independent control of the torque and flux control and an n-phase machine will remain to function with a revolving field in postfault operation up to n-3 phases are faulty.

Developments in the multiphase drive area have been usually based on utilization of two-level voltage source inverters (VSIs), with the machine’s stator winding in star connection and isolated neutral point. Various modulation techniques have been developed for various phase numbers, which take into account nature of the multiphase system and enable the realization of desired reference voltage on average in a switching period.

Although the use of multilevel inverter supply is well-established for three-phase drives, the same does not apply to multiphase drive systems. A few viable solutions to PWM control of multilevel multiphase VSIs have been reported only very recently and this is, beyond any doubt, one research direction that will be relevant in future as well.

The increased number of level in the output voltage decreases the harmonics causing lower acoustic noise and Electro Magnetic Interference (EMI). The two most common multilevel inverter topologies are the diode clamped inverter and the cascaded inverter. The cascade multilevel inverter is made up of a series of single phase inverters, each with their own isolated DC bus [4-5]. The multilevel inverters can generate almost sinusoidal output voltage waveform from several separate DC sources. One of the advantages of this topology is the modular nature of the modulation, control and protection requirement of each bridge.

II. MODEL DESCRIPTION & CONTROL ALGORITHM

The model consists of the following building blocks:

a) Five Phase Multi-Level Inverter
b) Volts/Hertz Algorithm for control of an Induction motor drive.

Control Algorithm reads the speed of the induction motor and compare it with the reference signal. The error generated is processed by a PI Controller to give the
required slip speed. This slip speed is processed to give voltage and frequency required for tracking the desired speed. The variation of voltage and frequency is such that Volt/Hertz remains constant. The complete system is as shown in the Fig 1.

A. Five Phase Multi-Level Inverter

Fig 2 shows the implementation of single phase H-Bridge Cell. There are two H-bridge cell for each phase. Each cell consists of four switches and a dc source as shown. Different switching combinations determine different voltages such as V+, V- and 0. The number of levels in multilevel inverter depends upon the number of separate DC source. That follows the relation is \( m = 2s + 1 \), where \( m \) is no. of voltage level and ‘s’ is no. of separate DC sources. The output from the H-Bridges are quarter symmetry to generate a sine wave. Due to quarter wave symmetry even harmonics will be absent. As there are separate DC sources, that make freedom of selection of source, either from sunlight, wind or any other natural resources. Moreover, it does not require any capacitor or diodes for clamping. And due to multilevel, the output has low THD.

B. Sinusoidal Pulse Width Modulation (SPWM)

Conventional Sine PWM is used for generation of switching pulses by comparing the modulating signal with carrier signal

Where, the variable controlled output voltage can be obtained by controlling the amplitude modulation index. The variable frequency can be obtained by changing the frequency of reference signal of the output voltage. Fig 4(c) displays the reference and carrier signals for pulse generation. In the switching bipolar scheme is applied, in this scheme, the two legs of the full-bridge inverter switches are triggered simultaneously. Using \( V_{ref} \), five 72º degree displaced modulating signals are generated. This sine PWM is largely used in industrial applications due to simple control. The ratio of carrier and modulating signal frequency defines the pulses in a switching period. The modulating signal controls the inverter output frequency \( f_o \) and the amplitude modulation index \( m_a \) controls the amplitude of the output voltage. The frequency modulation index and amplitude modulation index is defined by the equation (1) and (2).

\[
m_f = \frac{f_{car}}{f_c} \quad (1)
\]

\[
m_a = \frac{V_c}{V_{car}} \quad (2)
\]

Where,

\( f_{car} = \) Carrier signal frequency (triangular signal),

\( V_c = \) Inverter carrier signal

\( V_{car} = \) Carrier signal level
$$f_c = \text{Control signal frequency (sine signal)},$$
$$V_{car} = \text{Amplitude of carrier signal},$$
$$f_r = \text{Amplitude of reference signal}.$$
The speed references and the load torque on the machine are applied in the following sequence and the system performance can be observed from fig. 6.

a. At $t = 0$ sec, the speed reference is 850rpm.
b. At $t = 2$ sec, load torque of 10Nm is applied.
c. At $t = 3$ sec, the load torque is reduced from 10Nm to 5Nm.
d. And At $t = 4$ sec, there is a change in load torque from 5Nm to 2Nm.

### Table I. Motor Parameters

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Power (kW)</th>
<th>Voltage (V)</th>
<th>Pole pairs</th>
<th>Speed (rpm)</th>
<th>Rotor resistance (Ω)</th>
<th>Stator resistance (Ω)</th>
<th>Stator Inductance (mH)</th>
<th>Rotor Inductance (mH)</th>
<th>Inertia (kg.m$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specifications</td>
<td>3</td>
<td>230</td>
<td>3</td>
<td>850</td>
<td>15.5</td>
<td>25.3</td>
<td>103.1</td>
<td>92.2</td>
<td>0.021</td>
</tr>
</tbody>
</table>

Fig 7 shows the speed and torque response of the system for given speed references and load torque demands.

![Fig 7 Speed and torque response of the controlled system](image1)

Fig. 7  Speed and torque response of the controlled system

At starting, the machine steadily rises to approach the required steady state speed. Once the motor reaches its steady state speed, the torque developed by the motor is reduced as there is no more requirement of acceleration of the motor. The modulating signal shown in Fig 8, varies accordingly to keep the ratio Volt/Hertz constant. It can be observed that the frequency of the modulating signal is low at the starting with corresponding magnitude keeping V/f constant.

At $t = 2$ sec, the load torque demand is increased to 10Nm. For stable region operation, the speed should rise when there is a sudden decrease in load torque. The speed increases momentarily and then control algorithm brings it back to the desired speed. Fig 9 shows the output voltage of phase A of five phase inverter. Since appropriate switching technique is implemented, multilevel output is obtained. The phase difference between the two phases is also maintained at 72º by the control algorithm. This can be clearly observed by the modulating signal waveform shown in Fig 10.

![Fig 8 Variation of modulation signal magnitude and frequency during Volt/Hertz control](image2)

![Fig 9 5 Level Output Voltage of five phase Inverter](image3)

![Fig 10 Modulating signal for five phase inverter generated by the control algorithm](image4)

**IV. CONCLUSION**

The paper discusses multilevel inverter fed five phase Induction Motor drive controlled by closed loop Volt/Hertz Algorithm. A brief review of the operating principle is provided. The main focus is on the analysis of speed control in different load changing conditions. The transient for the drive is analyzed that confirms the speed control of the closed loop drive during conditions of load
change as well as transients. The response of the drive also validates its operation in the stable operating region. Five phase inverter is successfully implemented using a Multi-Level Inverter.

REFERENCES


